B68 12019

BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

SUBJECT: Space Storable Stage Atop the Titan IIIX (1205)/Centaur for Grand Tour Missions - Case 103

DATE: December 5, 1968

FROM: A. A. VanderVeen

ABSTRACT

It has been speculated that the space storable ($FLOX/CH_4$) Mars orbiter stage defined by a recent Lockheed study might provide an adequate payload capability for a Jupiter swingby outer-planet grand tour mission when installed atop a Titan IIIX/Centaur. It was found that such a configuration can place gross payloads of 1700-2700 lbs on appropriate trajectories in any of the 1976-1980 opportunities. Guidance requirements are considered, and net payload capabilities are presented.

(NASA-CR-100229) SPACE STORABLE STAGE ATOP THE TITAN 3X /1205//CENTAUR FOR GRAND TOUR MISSIONS (Bellcomm, Inc.) 10 p

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MEMORANDUM FOR FILE

Introduction

A query was received from W. W. Wilcox, NASA/RP, concerning the performance capability of a Titan IIIX/Centaur topped with the FLOX/CH_4 stage investigated as a Mars orbiter stage during a recent OART-sponsored study by Lockheed(1). Interest was expressed in the possibility that this vehicle configuration could deliver a payload in the neighborhood of 1500 lbs onto an outer-planet grand tour mission utilizing a Jupiter swingby.

Trajectory Requirements

A sequence of Jupiter-swingby outer-planet grand tour mission opportunities occur at thirteen month intervals beginning in 1976 and ending in 1980(2,3). The Jupiter swingby imparts sufficient energy to the spacecraft to allow escape from the solar system. Because of a fortuitous geometrical configuration of the planets in the late 1970's, Saturn, Uranus, and Neptune become more-or-less aligned, so that the spacecraft can encounter each planet in turn on its hyperbolic escape trajectory.

The minimal energy requirements vary slightly over the 5-year span of opportunities with a two-week launch window available during any year. A characteristic velocity (V_c) of 48,000 fps is sufficient to acquire appropriate minimal energy trajectories in 1976 and 1978, whereas 49,000 fps accommodates similar trajectories in 1977, 1979, and 1980.* Increases in energy above these minimums provide trajectory flexibility in the form of increased launch window and shortened trip durations; however, above a V_c of 52,000 fps the trajectories tend to graze Jupiter as the required turn-angle is achieved.

*Characteristic velocity, V_c, is the velocity the vehicle would have at a 100 nm perigee altitude on a conic trajectory whose energy corresponds to burnout conditions which can be achieved for the specified vehicle and payload.

VEHICLE PERFORMANCE

It should first be noted that the Titan IIIX(1205)/Centaur can deliver a gross payload of 2,240 lbs to a V_c trajectory of 48,000 fps or a 1,740 lb payload to one of 49,000 fps. Thus it would appear that the mission can be accomplished without the use of the FLOX/CH_4 stage. However, these values, which may be determined from the performance curve of Figure 1, do not account for midcourse propulsion which could represent a significant fraction of the gross payloads.(4) The attractiveness of using the FLOX/CH_4 stage for this mission, therefore, rests largely on how much additional payload capability it can provide.

Table 1 shows the propulsion system characteristics and weights for the FLOX/CH_4 stage.

TABLE 1 - FLOX/CH_4 Stage System

Characteristics and Weights

Propellant	FLOX/CH_4
Thrust	8,000 lbs
Isp	410 secs
Propellant Weight	6,485 lbs
Stage Weight (Full)	7,968 lbs

An approximate performance curve for the specified vehicle configuration can be obtained by adding the theoretical ΔV of the FLOX/CH_4 stage to the characteristic velocity of the Titan/Centaur for each payload considered as follows. The 7,968 lb stage weight plus the payload carried by the FLOX/CH_4 stage represents a gross "payload" launched by the Titan/Centaur. A corresponding value of V_c can be determined for the Titan/Centaur from Figure 1. With the initial and final weights of the FLOX/CH_4 stage known, its theoretical ΔV can be calculated from the familiar rocket equation

$$\Delta V = gI_{sp}\ln(W_o/W_f), \qquad (1)$$

where g is the gravitational acceleration (fps^2)

I_{sp} is specific impulse (sec)

W_o is the initial weight (lbs)

and W_f is the final weight (lbs).

This procedure was used to generate the solid curve of Figure 2.

The results of this first-cut investigation looked sufficiently attractive to warrant further analysis. It was recognized that the solid curve of Figure 2 represents optimistic results, because the rocket equation does not account for the FLOX/CH_4 stage gravity losses, and because the impulsive ΔV was assumed to be applied at 100 n.mi. altitude perigee, whereas the TIIIX/Centaur burnout and the fourth stage ignition actually take place at higher altitude. A representative set from J. Edgar, Martin-Marietta, Denver, who had been studying the Centaur's application for a 1973 Mars Mariner-type mission. The payload used in his study was less than the stage weight without payload considered here so a direct correlation could not be made; however, he felt that a burnout altitude of 315 n.mi. was quite representative for this applications.

The Titan/Centaur V_c values at 100 n.mi., Figure 1, were used to determine the velocities the Centaur would have at 315 n.mi., if it were to follow a constant-energy trajectory (conic). The ideal ΔV's were then added to these velocities to determine new energies and corresponding V_c's at 100 n.mi. These results are shown in Figure 2 by the long-dash curve.

To obtain an estimate of the gravity losses of the FLOX/CH_4 burn, which are not accounted for when Equation 1 is used, the final stage burn-trajectory was integrated by means of a suitable computer program. Starting from the same Centaur burnout conditions and ending with the specified energy, a 149 lb decrease from the nominal payload value of 2500 lbs at V_c = 50,000 fps resulted. This corresponds to a velocity gravity loss of 315 fps. The payload decrement is indicated by the dot in Figure 2 with the dot-dash curve extrapolated throughout the range of interest. This performance curve should be fairly representative for the four-stage vehicle configuration.

NAVIGATIONAL GUIDANCE REQUIREMENTS

Navigational ΔV requirements for a grand tour of the outer planets is largely a matter of speculation; however, A. L. Friedlander has investigated the subject with considerations for using earth-based radar or an on-board celestial system.(5)

Friedlander considers the 1977 and 1978 opportunities and determines separate ΔV requirements for missions passing through the rings of Saturn and also missions during the same years that pass external to the rings. A good case is make for on-board celestial navigation systems from the reduced ΔV requirements standpoint. Table 3 summarizes Friedlander's results, in which he considered 8-10 maneuvers for each trajectory.

TABLE 3 - Navigational ΔV Requirements

	1977 E	1977 I	1978 E	1978 I
	m/sec (fps)	m/sec (fps)	m/sec (fps)	m/sec (fps)
Celestial On-Board	190 (624)	428 (1405)	203 (666)	372 (1220)
Radar Earth-Based	450 (1475)	1712 (5620)	354 (1160)	1010 (3310)

*E - External, I - Internal.

From this table it is reasonable to assume a 1,000-2,000 fps ΔV range as representative of the grand tour guidance-propulsion system requirements.

GUIDANCE PROPULSION SYSTEM

The gross payload curves of Figures 1 and 2 contain no provision for midcourse guidance maneuvers. The $FLOX/CH_4$ stage, though classified as "space storable," can not be considered suitable to provide midcourse impulses without a throttling capability, and additional insulation and increased meteoroid shielding may be required. It was therefore assumed that the gross payload curves include the weight of a propulsion system and propellant load to be used for guidance corrections.

A mono-propellant (hydrazine) system was assumed, having a 30 lb thrust and 230 I_{sp}. Engine, structure and propellant weights were determined for 1,500 and 2,500 lb payloads and 1,000 and 2,000 fps ΔV requirements.* The net payloads were then determined and plotted on Figures 1 and 2.

RESULTS

The lower curves of Figures 1 and 2 show realistic estimates of the net payload delivery available with the specified vehicle configurations when a reasonable guidance capability is provided. The attractiveness of adding the $FLOX/CH_4$ stage to the Titan IIIX/Centaur can be evaluated by comparison of the figures, a summary of which is presented in Table 4.

TABLE 4 - Payload Comparison (lbs)

	76 or 78 Min Energy		77,79 or 80 Min Energy		V_c=50,000 (Typical)		V_c=52,000 Max Energy	
Guidance ΔV	1000 fps	2000 fps	1000 fps	2000 fps	1000 fps	2000 fps	1000 fps	2000 fps
TIIIX/ Centaur	1930	1670	1500	1300	1020	930	-----	----
TIIIX/ Centaur/ ($FLOX/CH_4$)	2640	2260	2300	1950	1980	1700	1420	1200
Difference	710	590	800	650	960	770	1420	1200

The table shows that the addition of the $FLOX/CH_4$ stage increases the net payload capability of the Titan IIIX/Centaur vehicle by 30 to 50 percent for the minimal energy missions. A sizeable payload capability is retained throughout the higher energy trajectory range, providing mission flexibility that could not otherwise be considered.

CONCLUSIONS

The application of the $FLOX/CH_4$ stage placed atop the Titan IIIX(1205)/Centaur is found to greatly enhance the payload delivery capability of the vehicle for grand tour missions to the

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*Communication with A. E. Marks, Bellcomm, Inc.

outer planets. A net payload of from 1200 to 2000 lbs can be delivered while retaining full freedom of trajectory selection during any of the five opportunities in the late 1970's.

The intent of this study was only to evaluate the performance of the FLOX/CH_4 stage, previously proposed for a Mars orbiter application, for the specified mission, It should not be construed that other stages, such as a Burner-type or others, would not provide similar payload enhancements. However, the results provide a good example of FLOX/CH_4 stage application.

A. A. VanderVeen

1013-AAV-nma

Attachments
References
Figures 1 - 2

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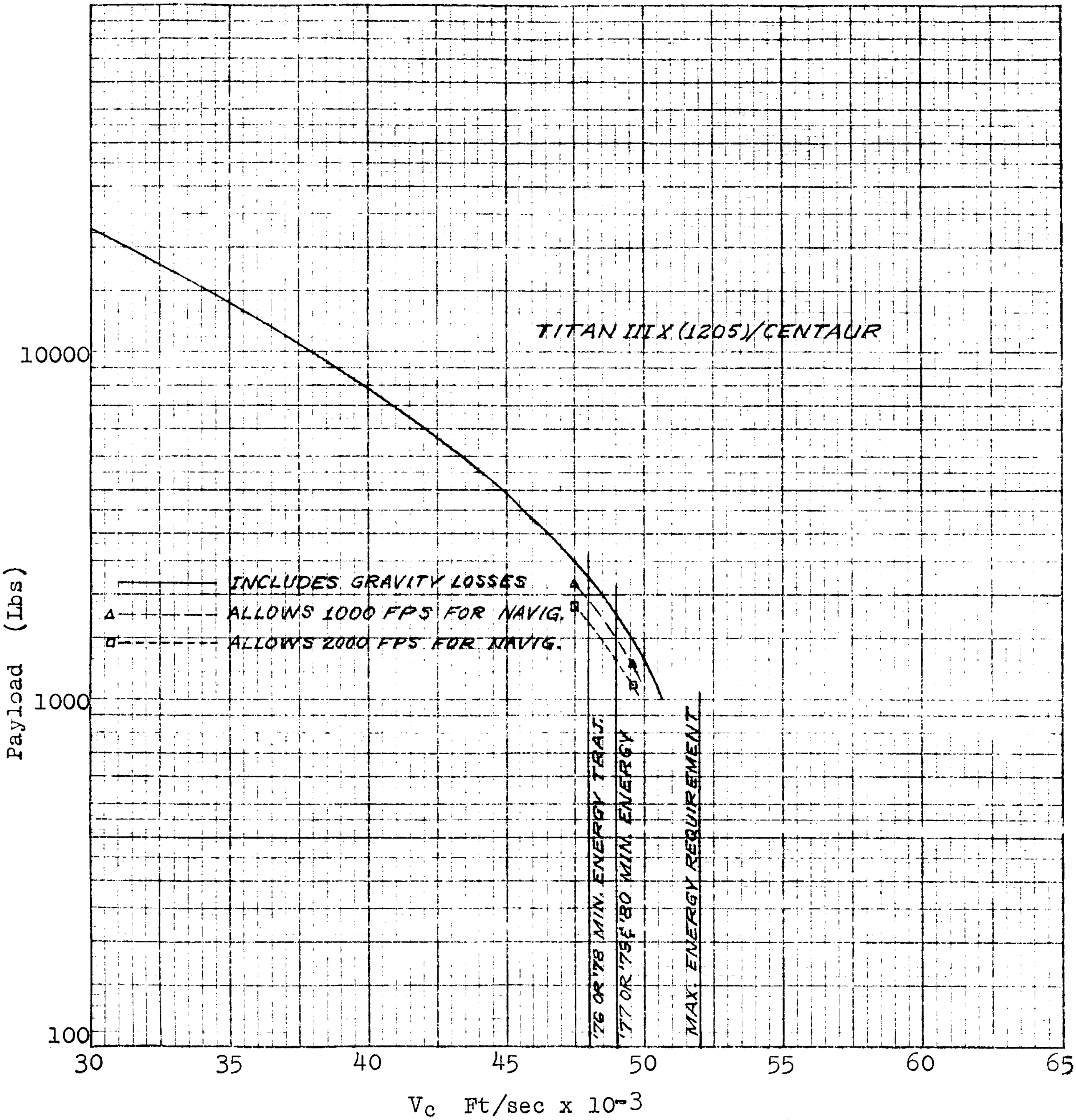

Fig. 1 Performance curve for the Titan IIIX (1205)/Centaur Vehicle

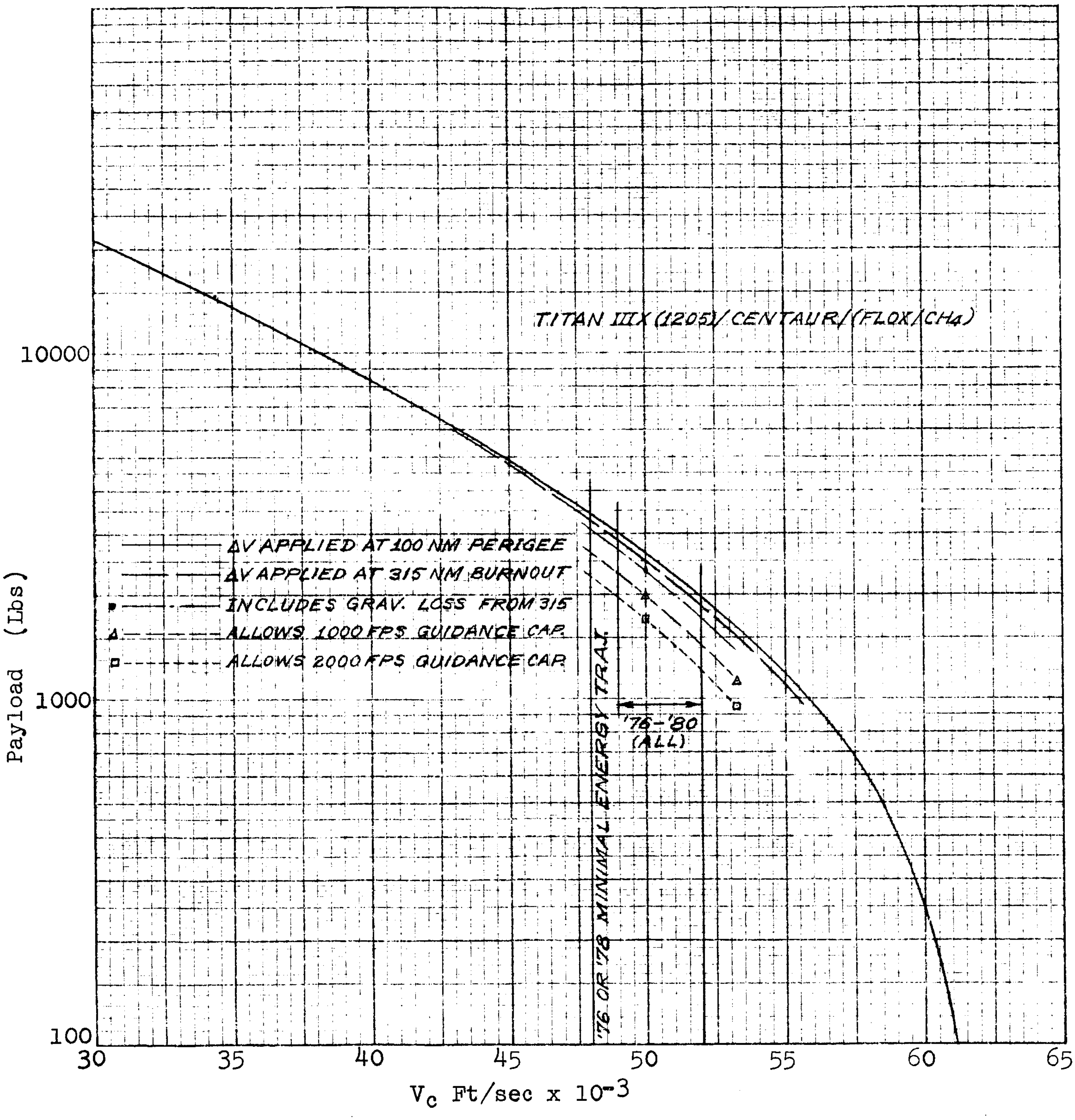

Fig. 2 Performance curve for the Titan IIIX (1205)/Centaur with the $FLOX/CH_4$ fourth stage.

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